



HISTORY OF ICE PROTECTION SYSTEM DESIGN AT BELL HELICOPTER

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Bell Helicopter Model Timeline



M47



M206L4



M407



M427



UH-1



222



M412



M430



UH-1Y



214ST



AH-1Z



XV-3



XV-15



V22



UAV



BA609

1941 1945 1956

1977

1982

1991

1994

1999

M47

- The earliest formal documentation retrieved addressing a Bell Helicopter in icing or snow is a report of a Model 204A tested at Mt Washington in 1962. However, there are photographs and undated papers that indicate that the Model 47 was tested at Mt Washington and had accumulated ice on its blades at least as early as 1958



HISTORY OF ICE PROTECTION SYSTEM DESIGN AT BELL HELICOPTER

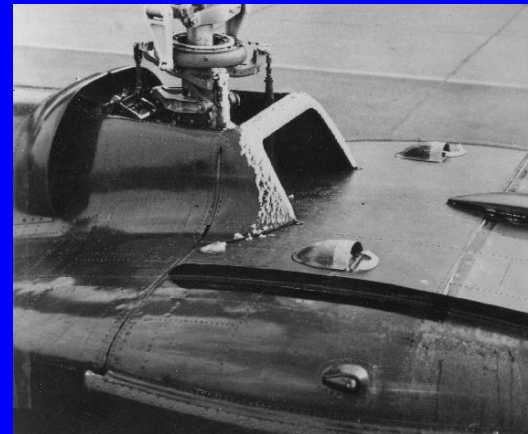
- Inadvertent icing certification
- Research and Development
- Tiltrotors

Inadvertent Icing Certification

- Long before the technology was developed to protect rotorcraft and allow operation in known icing conditions, the helicopter engine air induction systems were designed and tested to demonstrate that such systems would be capable of providing enough power to the rotor blade to allow the helicopter to exit inadvertent icing.
- All of the Bell Helicopter commercial model's engine air induction systems and most of the military models were qualified by test or by similarity to previous installations already approved. Paragraph 7.461(a) of the Civil Air Regulations made a requirement that engine air induction systems shall incorporate means for the prevention of ice accumulation. Section 1093(b) of FAA 14 CFR Part 27 (Normal category rotorcraft) and Part 29 (Transport category rotorcraft) require demonstration that each turbine engine and its air inlet system can operate throughout the flight power range of the engine (including idling) in icing conditions specified in Appendix C of 14 CFR 29, in snow both falling and blowing, and ground fog without adverse effect on engine operation.

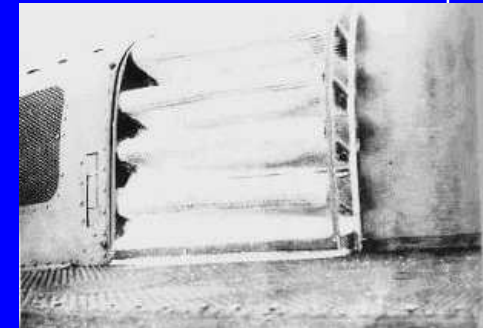
Bell Helicopter Engine Inlet Designs

The earliest formal documentation concerning icing was the substantiation of the Model 204B of the inlet icing requirements for the U.S. Federal Aviation Administration (FAA). The tests were conducted at Mt Washington Icing Establishment for the qualification of the Lycoming T53-L1 engine in 1962. The test demonstrated that it was possible to design a satisfactory engine air induction system without deicing the airframe part of the inlet.



UH-1C and UH-1D

A Model UH-1C and UH-1D were tested in an artificial icing cloud at the National Research Council (NRC) of Canada at Ottawa, Canada during the 1967 winter to evaluate various engine inlet configurations and the Model 540 rotor with Polyethylene tape installed on the leading edge at the main rotor blade in light to heavy icing conditions.



Some of the conclusions from the test were:

- The inlet barrier filter configuration with a fine mesh screen was not acceptable for operation in icing conditions
- The erosion resistance of the Polyethylene tape was inadequate and the ice-phobic quality unsatisfactory for use on leading edge of rotor blades in icing conditions.
- The pressure differential sensing device provided adequate warning for the pilot of an icing condition when used in conjunction with the barrier filter and fine mesh screen.

206, 407, and OH-58s

The model 206 is the Bell Helicopter model with the greatest number of different versions: 206, 206A, 206B, 206L, and 206LT. Although not keeping up with the 206 family designations, the model 407 could be also considered as a modernized extension of the 206 product line and the TH-57, TH-67, and the OH-58, being the military line of the 206s.

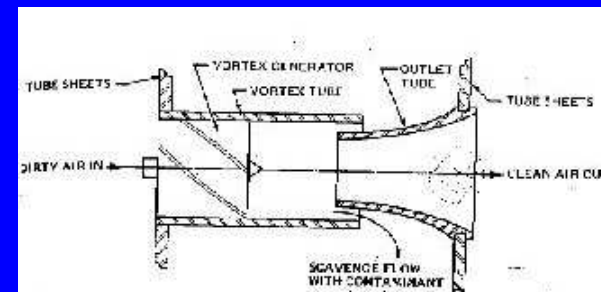


In 1972 a model 206A was tested at the NRC facility with the use of a “snow-making machine” to develop a suitable engine inlet configuration. The helicopter was weighted with lead ingots and was operated at 100% rotor speed and equivalent power to fly 30 mph for 90 minutes. The ship was then unloaded, without shutting down, and flown at MC power to airspeed in excess of 90 mph.

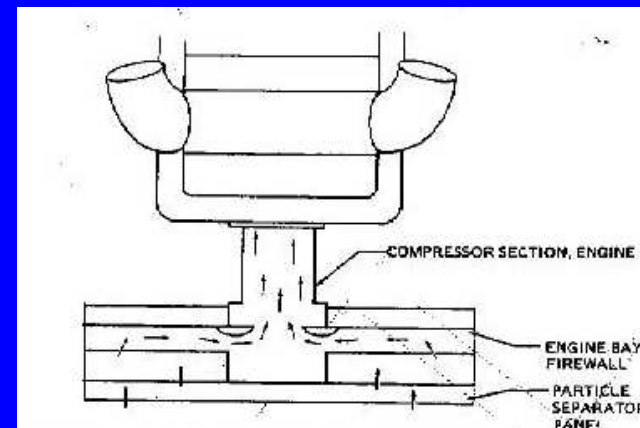
206, 407, and OH-58s

The difficult development process to obtain a final inlet configuration resulted in:

- 37 tests
- 20 inlet configurations and combinations
- 24 engine flameouts



The final configuration consisting of a particle separator (CENTRISEP) and a deflector baffle kit was tested in natural snow conditions and demonstrated that the installation could operate in snow environment corresponding to one half mile or less for 20 minutes.



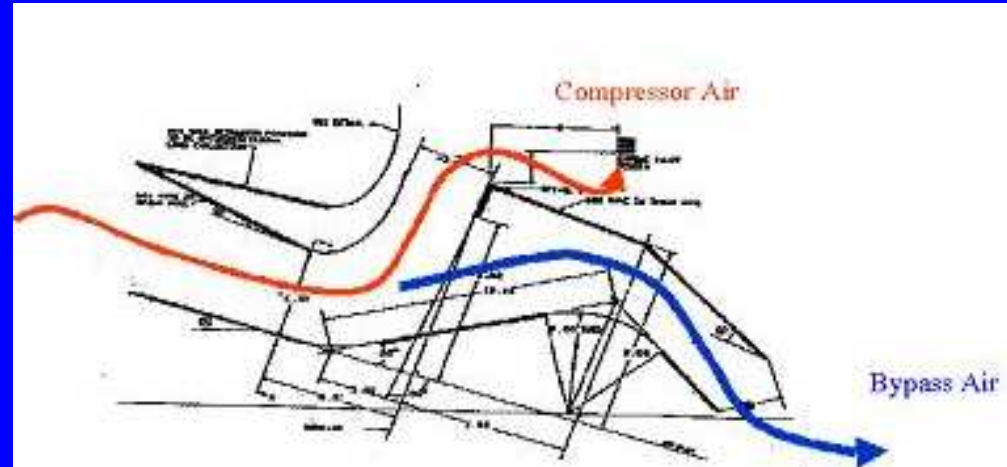
427

The twin engine Model 427 uses side and slightly aft facing CENTRISEPs, one per engine. The CENTRISEP tube arrangement was carefully optimized in order to capture the downwash effect from the rotor while improving the scavenging efficiency of the particle separator. A series of flight tests performed with different percentages of CENTRISEP blockage identified the critical engine performance condition. The established data base on CENTRISEP blockage for different icing conditions and additional specific conditions allowed to determine that Model 427 operating envelope would not be limited by engine power reduction due to air induction blockage.



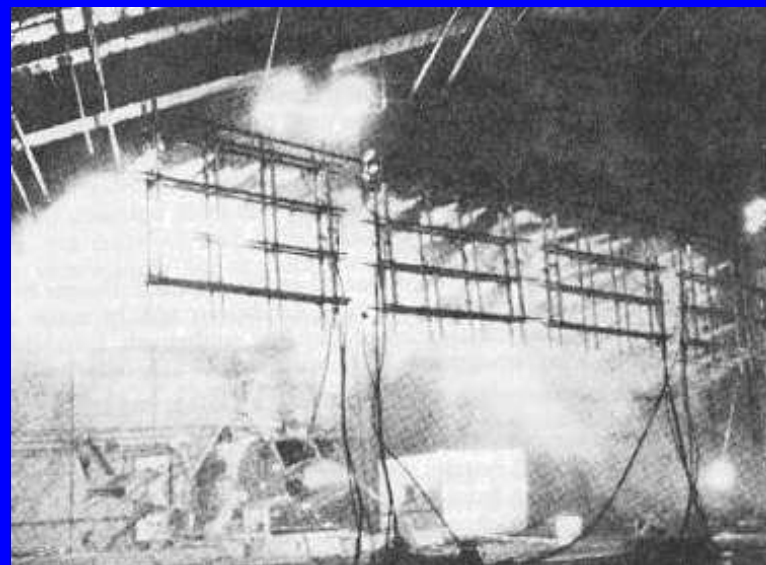
214, 212, 412, 222 and BA609

Since 1965 some applications of the PT6 turboprop engine have been protected against icing hazards by inertial separation systems developed by PWC. This type of ice protection design has been successfully carried over the Bell Helicopter models 214s, 212s, 412s, 222s, and BA609 with slight variations to accommodate each installation.



214, 212, 412, 222 and BA609

Artificial icing tests were conducted in the McKinley Climatic Laboratory, Eglin Air Force Base, Florida, to evaluate the 214A helicopter when exposed to icing conditions. Approximately 34 hours of total aircraft operation time were logged between November 1975 and February 1976. A 9 by 60 foot spray with 65 nozzles suspended 13.5 feet above the floor and 12 feet from the rotor tip in front of the aircraft. The cloud was blown onto the rotor disk by three 100 horsepower fans placed 52 feet behind the spray frame.



214ST

The 214ST tests were conducted at the NASA Glenn Research Center (formerly the Lewis Research Center) Icing Research Tunnel (IRT) during the time period January 1981 to February 1981. A left hand engine air inlet was used and the tunnel facility blowers simulated engine airflows. The test showed that the engine air inlet and inlet duct performed acceptably throughout the engine power range and the aircraft airspeeds.



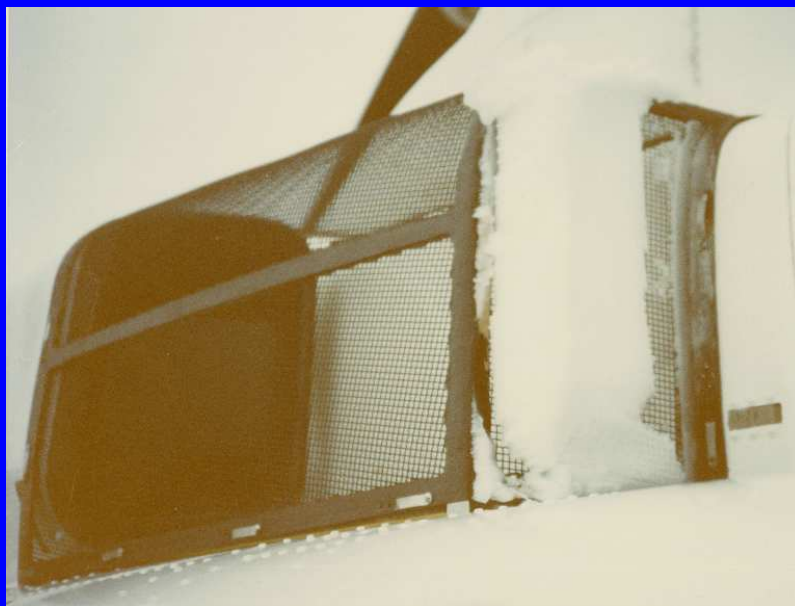
214ST

Artificial flight tests of the M214ST were conducted inside the NRC Icing Spray Tower cloud and behind the HISS between January and March 1982. Tests behind the HISS showed that ice accumulations on the engine inlet lip previously judged benign was ingested by the engine upon engine shutdowns in ambient temperature slightly above freezing.



214ST

While no damage was found upon borescope inspection of the engines it was recommended that ice ingestion be avoided at engine compressor speed less than 15% when the engine particle separation is not functioning. This experience resulted in an addition of an engine inlet screen that was evaluated in natural icing flight test. Natural icing test verified the need for the inlet icing screen. While initially only one inlet had been equipped with the screen the opposite engine was damaged due to ice ingestion.



214ST and 412EP

The performance of an unprotected Model 412 in icing was reviewed to attempt to establish, based on the extensive database accumulated, an operating envelope similar to the CAA approved on the Model 214ST. Icing conditions chosen for 412EP icing statement of performance allow comparison with competitive helicopters and are within 214ST approved icing flight envelope:

- Liquid Water Content 0.5 g/m³
- Air Temperature -7 °C
- Maximum Altitude 8,000 ft
- Gross Weight 11,000 lb
- True Airspeed 105 knots (95 KIAS at 8,000 ft alt)

In those conditions the Model 412EP can fly for more than 7 minutes while within MC power. Accessing the Takeoff power will provide more than 5 minutes necessary to exit the icing conditions. This analysis shows that the M412 requires an ice protection system including main and tail rotor to be certifiable to 14 CFR Part 29 Appendix C.

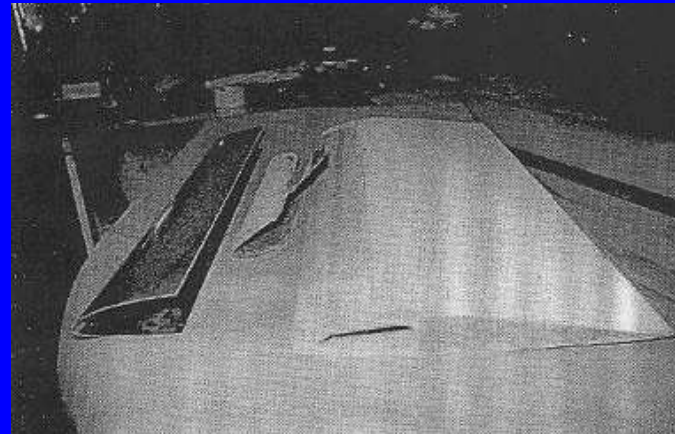
Research and Development

EIDI

A study was conducted in 1989 under a contract issued by the Canadian Department of National Defense (DND) to investigate the feasibility of using Electro Impulse Deicing system (EIDI) as a primary deicing system for helicopter rotors.

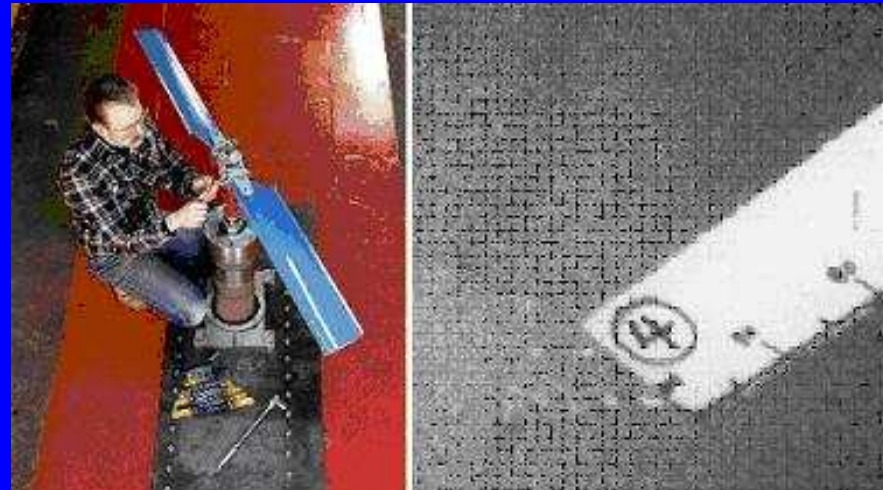
The feasibility study assessed impact on: Electrical system, dynamic characteristics, structural integrity, ice shedding, blade erosion, coils and coils location, operation and reliability, and damage tolerance.

The concept of low power deicing was shown to be a feasible technology for helicopter blades



Ice Shedding

A consortium composed of NASA, Texas A&M University, Bell Helicopter Textron, Boeing Helicopters, McDonnell Douglas Helicopters, and Sikorsky Aircraft endeavored in a program to better understand the impact of rotor blades ice accumulation on aircraft performance, increase in vibration and ice shedding. The program was to also validate the industry existing performance models and assessed the benefits of rotor blade scaled model testing



Ice Shedding

The initial experimental program was conducted in 1988 in the NASA Lewis Research Center Icing Research Tunnel (IRT) in which the OH-58 tail rotor assembly was operated in a horizontal plane to simulate the action of a typical main rotor. Ice was accreted on the blades in a variety of rotor and tunnel operating conditions and documentation of the resulting shapes was performed. Rotor torque and vibration were recorded and presented as functions of time for several representative test runs, and the effects of various parametric variations on the blade ice shapes are shown. This OH-58 test was the first of its kind in the United States. Although not a scaled representative of any actual full-scale main rotor system, this rig has produced torque, vibration, and both natural and forced ice shedding data, which will be useful in assessing the quality of existing rotor icing analyses.

NRTC/RITA

A National Rotorcraft Technology Center (NRTC)/Rotorcraft Industry Technology Association (RITA) project was established to improve and optimize rotor blade ice protection systems for conventional helicopters and Tiltrotor aircraft. The project trade study identified advanced electrothermal systems and electro-expulsive systems as being the most promising.

TRADE STUDY SUMMARY

Ratings prior to risk reduction tests

<u>CONCEPT</u>	<u>SUPPLIER</u>	<u>RATING</u>
ELECTROTHERMAL		
WOVEN WIRE (UH-60 BASELINE)		40.91
BASELINE WITH ADV. CONTROLLER		48.86
FOIL WITH ADV. CONTROLLER		43.06
SPRAYMAT WITH ADV. CONTROLLER		48.58*
COATED FIBERS/ADV. CONTROLLER		44.84*
ELECTRO-EXPULSIVE		
EEDS		58.35
EEDS		61.48
EEDS		60.13*
EIDI		33.91
PNEUMATIC		
SMALL TUBE		47.84
IMPULSE		58.08
SHAPED MEMORY ALLOY (SMA)		
SMA ONLY		34.75
SMA/ET HYBRID		33.55
ICE PHOBIC		
MATERIAL		42.79
CHEMICAL		41.36

Ratings after completion of risk reduction tests

ELECTROTHERMAL		
SPRAYMAT WITH ADV. CONTROLLER		50.56*
COATED FIBERS/ADV. CONTROLLER		50.45*
ELECTRO-EXPULSIVE		
EEDS INNOVATIVE DYNAMICS		53.96*

Differences of less than one point may not be meaningful.

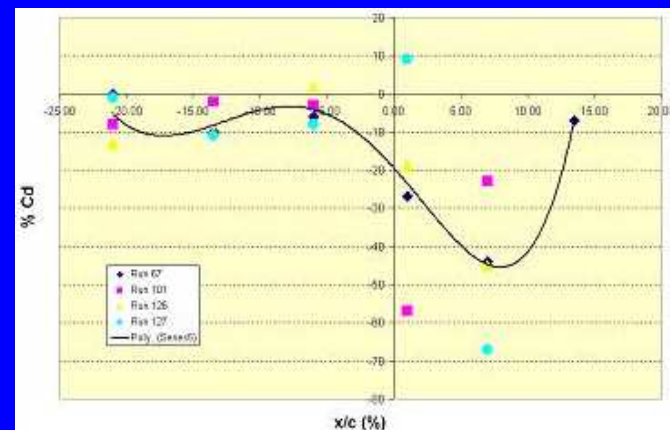
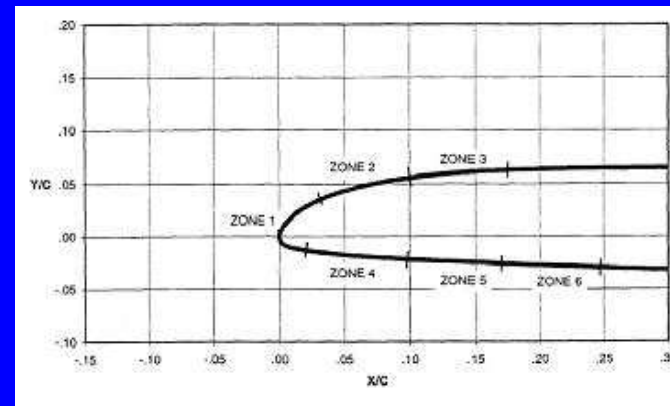
NRTC/RITA

The model spanned the six-foot height of the NASA IRT and had a 15-inch chord Sikorsky SC2110 rotorcraft airfoil.



NRTC/RITA

In the absence of centrifugal forces the chordwise electrothermal systems removed ice more efficiently than the spanwise systems. The chordwise design was more efficient at utilizing the heat provided in the adjacent (spanwise) zones. The upper surface heater coverage only needs to be no more than 9% and the lower surface heater coverage of 24% removed most of the ice and proved to be desirable. However, the removal of ice on zones 5 and 6 on the lower surface (beyond 8% chord) provided only small reduction in the drag increase due to icing.



Ice Accumulations Prediction with CFD

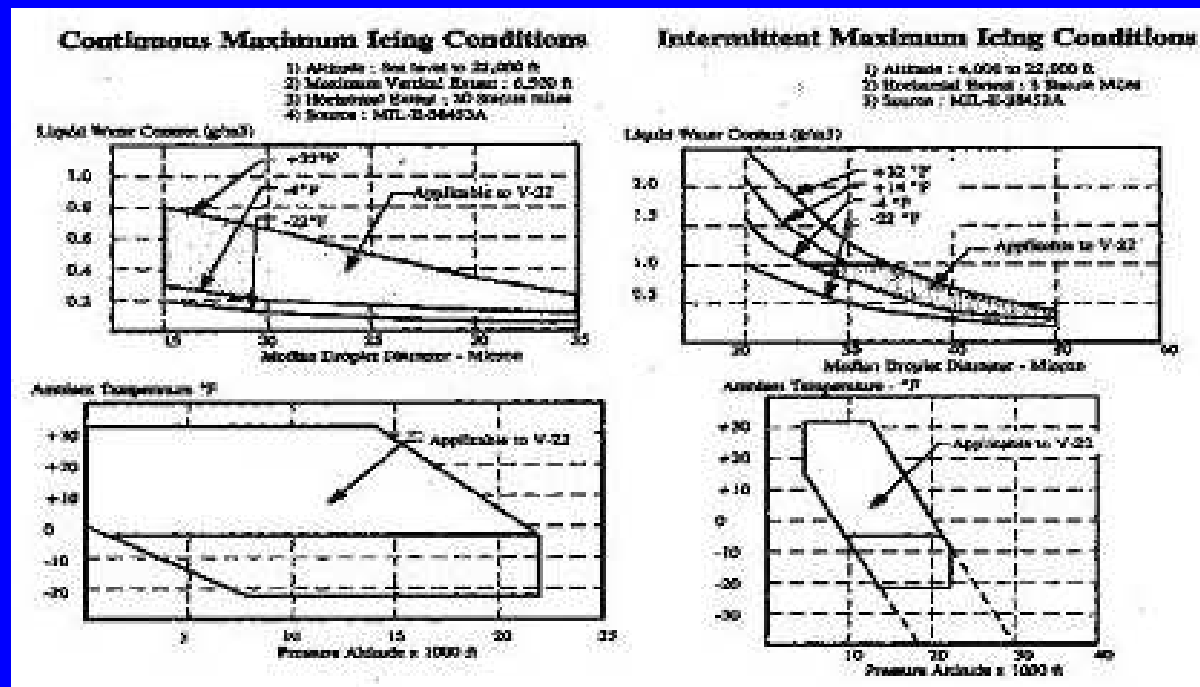


Tiltrotors



Tiltrotors

Bell Helicopter is engaged in several Tiltrotor projects such as the MV-22/CV-22, the BA609 and UAVs to different extents. The V-22 and the UAV ice protection systems are to be qualified to Military requirements (Medium and Light icing).



V-22

The design and status of testing of the V-22 Ice Protection System was summarized in earlier paper (Montreal '95). Evaluation of the aircraft in clear air and natural icing environment began in winter 2000 and will resume during the winters of 2003 and 2004. The selected V-22 aircraft will be configured such that all different versions of the aircraft (MV-22 and CV-22) will be qualified simultaneously.



V-22 Wing Boot Configuration

Flight-testing revealed that the V-22 tail configuration was sensitive to auto-inflation of the wing boots during specific maneuvers. At the time the wing boot design used a spanwise tube arrangement. Research performed by NASA concluded that spanwise and chordwise design had generally the same ice-removal characteristics but the chordwise design generated less drag when inflated. Upon detail review of the NASA test results the boot tube arrangement was changed to a chordwise configuration and tested in the BFGoodrich icing tunnel.

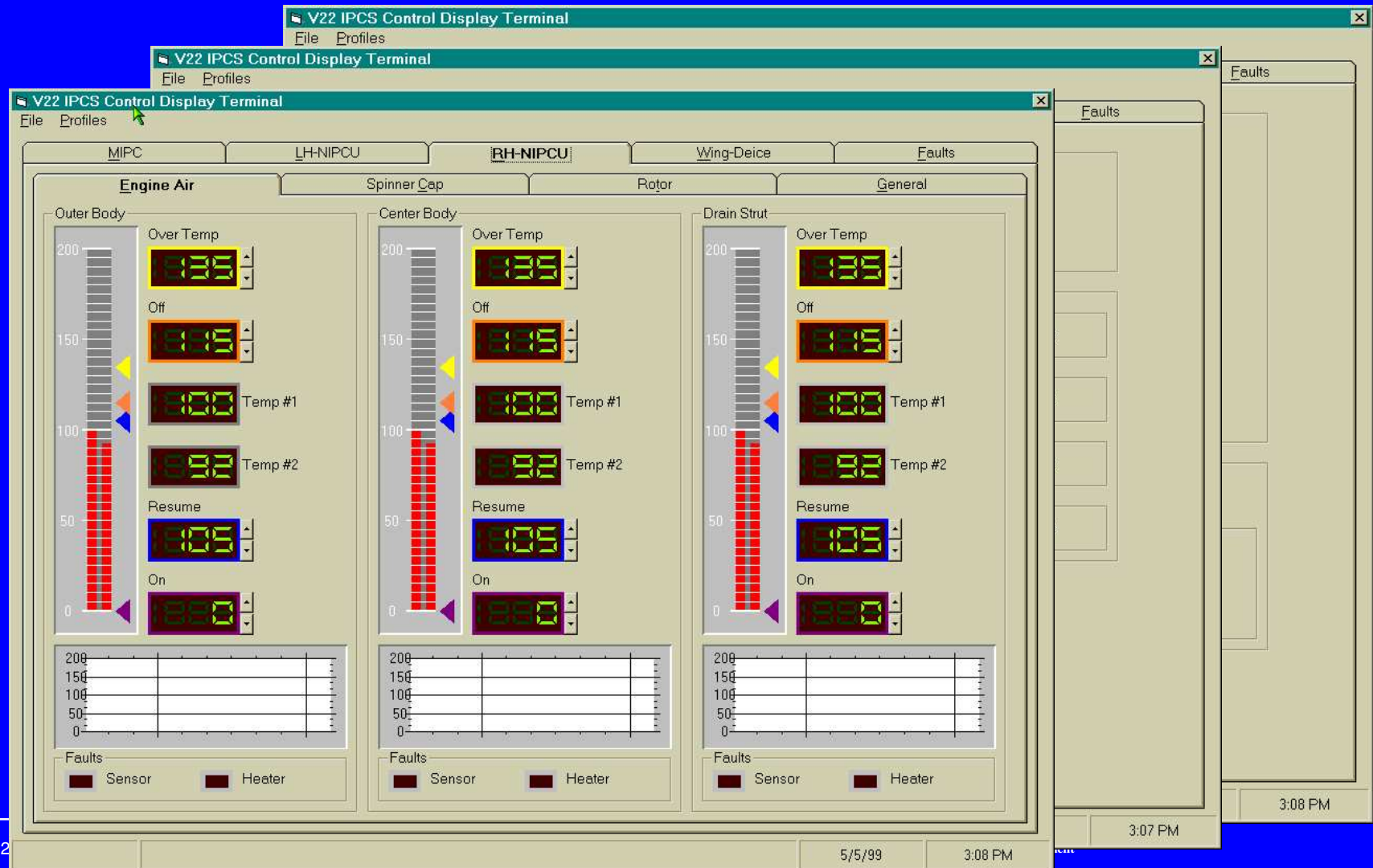


Flight Testing Efficiency

In order to maximize the efficiency of the testing in the clouds, the aircraft will be fitted with a Control Display Terminal allowing the flight test engineers on-board to make immediate adjustments to the IPS control within previously established boundaries. This feature allows the aircraft to be self-sufficient during the testing although the V-22 constantly maintains radio contact with the ice protection engineer in the chase aircraft and the ground support crew.

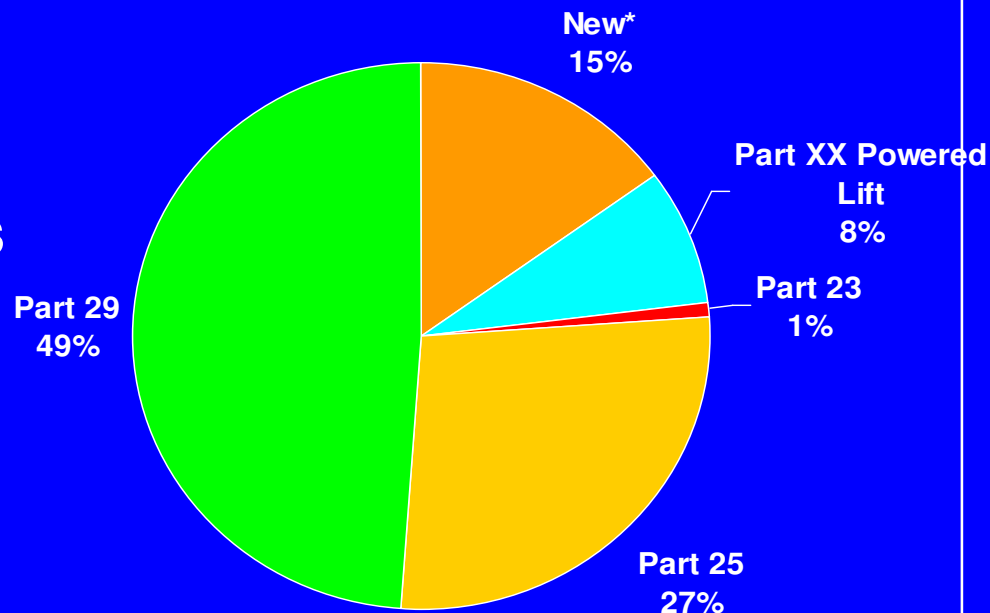


Flight Testing Efficiency



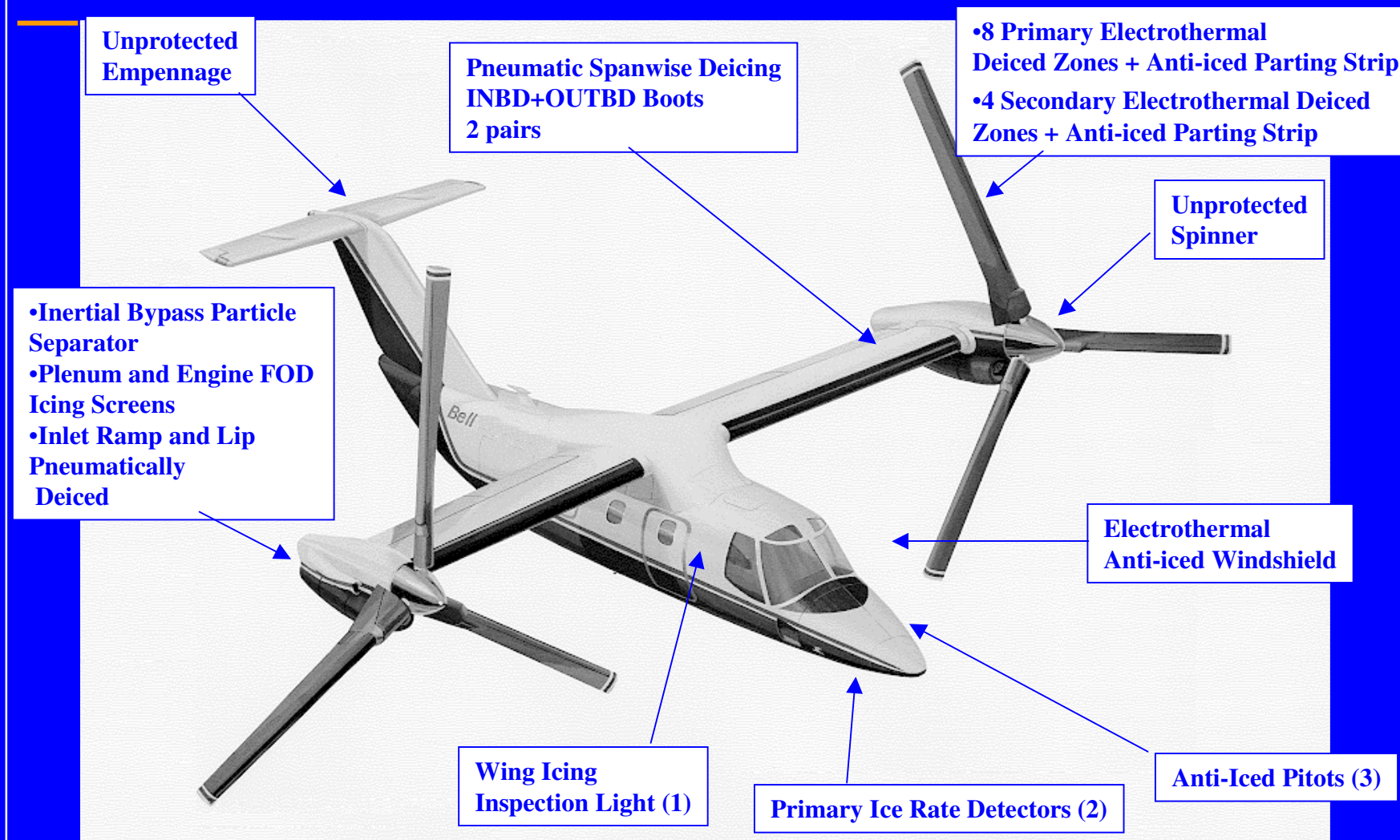
BA609 Certification Basis

The BA609 is to be certified to combinations of 14 CFR Parts 23, 25 and 29 and the entire envelope defined by 14 CFR 25 Appendix C.

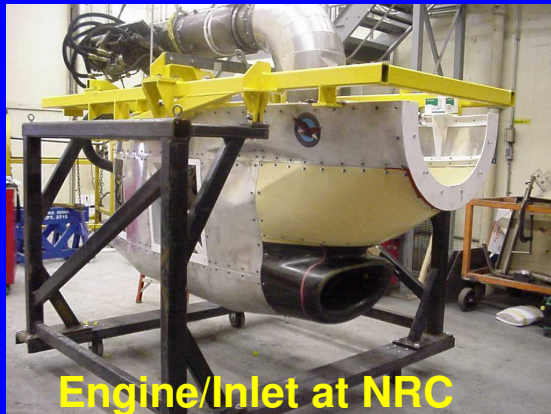


* Most are paragraphs from Parts 25 and 29 modified to reflect tiltrotor characteristics

BA609 ICE PROTECTION DESIGN



BA609 Icing Tests



Engine/Inlet at NRC



Impact Test at BHC



Blade(s) in BRAIT



Vertical Tail in IRT



Horizontal Tail in IRT



Spinner/Inlet in IRT



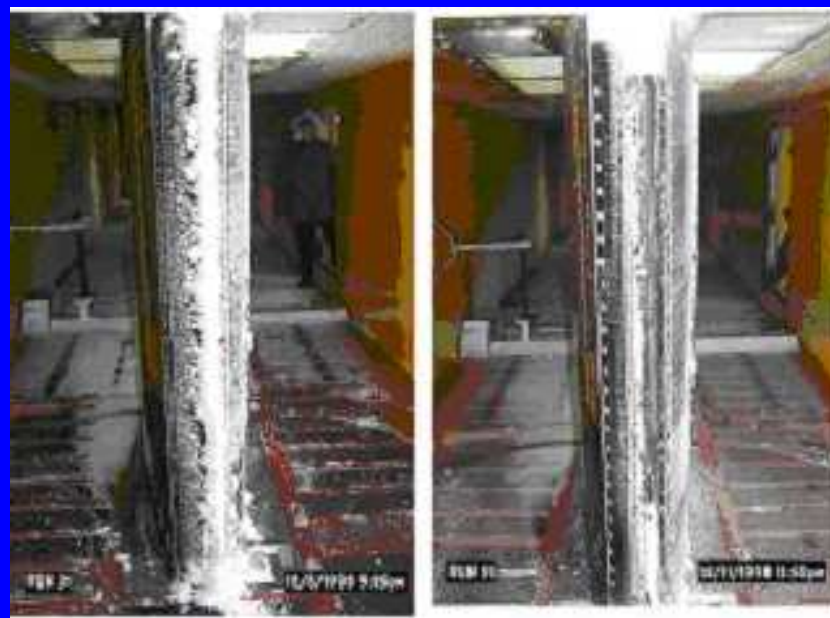
Wing in IRT

BA609 Wing

A full-scale model of the aircraft outboard wing section was tested in the NASA IRT during the months of December 1998, March 1999 and April 1999

Several variables were evaluated:

- Chordwise and spanwise pneumatic tube arrangements
- Different inflation pressures
- Different deicing thickness
- Fuel Bags Vent Design



BA609 Wing

- In general the results obtained from the measured ice accumulation thickness compared reasonably well with the predicted thickness using the ice-rate detector counts.
- Only small improvements were noticed when deicing the wing with increased pressure.
- The spanwise tube design visually deiced better than the chordwise arrangement and showed slightly lesser drag and lift penalties. Auto-inflation of the spanwise design was simulated and drag and lift changes recorded. No noticeable change of lift and drag were recorded for the conditions tested
- The wing flaperon hinge moment at all times even during Supercooled Large Droplets (SLD) testing, remained well within the capability of the aircraft hydraulic system.

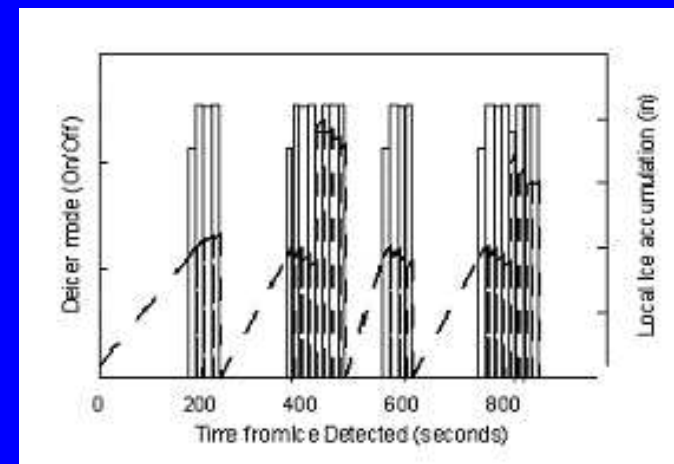
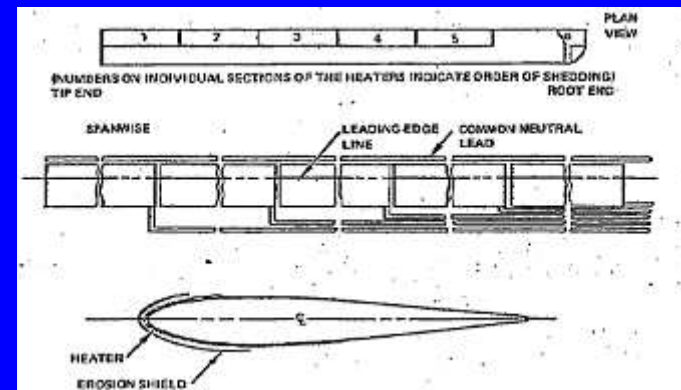
BA609 Rotor

Each rotor system of the BA609 is composed of 3 blades and one spinner. The spinner is not protected and allows ice to accumulate on its surface. A painted line around the spinner body provides visual indication to the crew of icing conditions in excess of the 14 CFR Appendix C.

Each blade ice protection system includes a primary and a secondary electrothermal system. The primary system is composed of an anti-ice parting strip running from the tip of each blade down to mid span and eight electrothermal deice zones. The function of the parting strip is to reduce the size of ice shed particles that will impact the side of the cabin in airplane mode.

BA609 Rotor

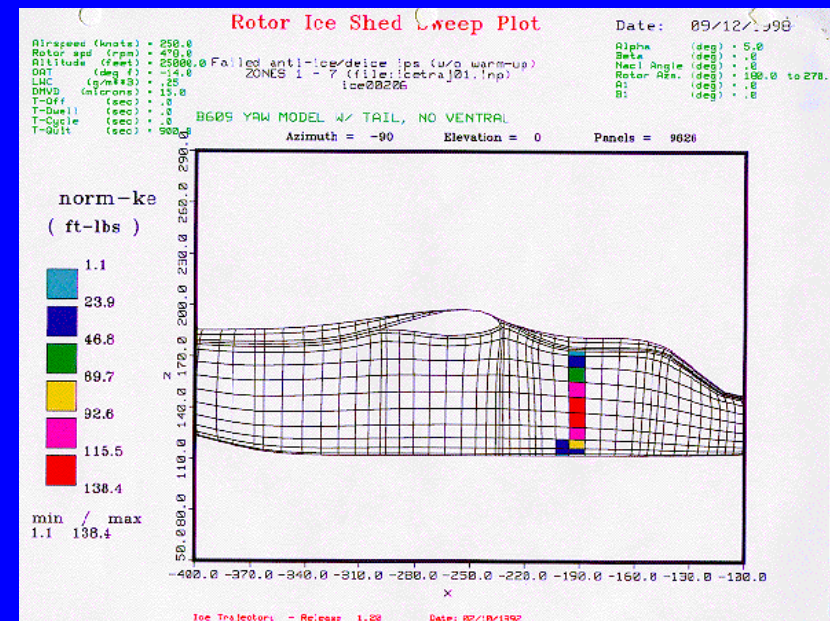
The deicing sequence of the rotor starts from the blade tip down to the mid-span zone for the first cycle and then from the tip down to the hub for the second cycle



Rotor Ice Shedding Trajectory

Abstract from FAA Icing Handbook :

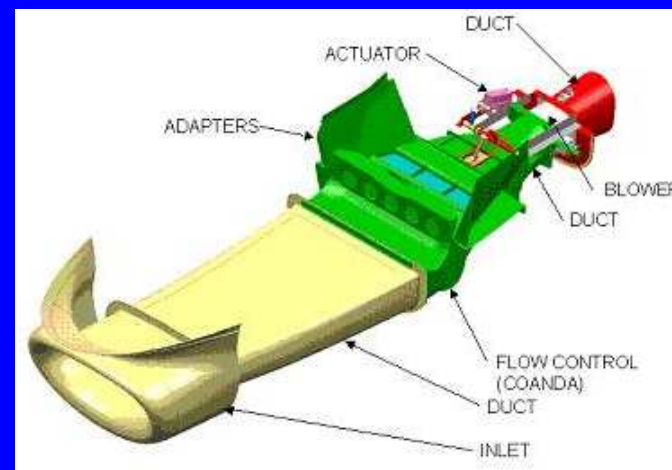
“Modeling ice pieces of random shapes is a statistical problem. Extreme cases of weight and aerodynamic coefficient (C_l and C_d) should be used. If the ice chunk rotates about its own center of mass, C_l and C_d values will vary. Again, the conclusion of AGARD Advisory Report No. 223 is that, because of the assumptions and simplifications made, ice shedding trajectory computations should be used cautiously and substantiated by in-flight tests. However, it is felt that despite these restrictions, the computations can be used as a flight test, development, and certification aid”



BA609 Engine Inlet

In an effort to reduce the cost of certification of testing the engine and the inlet system each independently, Bell Helicopter and PWC combined resources and tested the engine and the inlet system together at the National Research Council (NRC) Engine Laboratory, Ottawa, Canada.

Preliminary testing was conducted without inlet lip and inlet ramp protection. Analysis of the results showed that due to inlet losses from the ice accumulation translated in unacceptable engine performance degradations. Pneumatic deicers were subsequently installed and resulted in great reduction in engine performance impact



0.15 Scale Model

A 0.15-scaled BA609 unpowered force and moment model was tested in the Texas A&M 7x10 feet wind tunnel in August 1999 to evaluate aerodynamic impact of simulated ice on the aircraft performance.

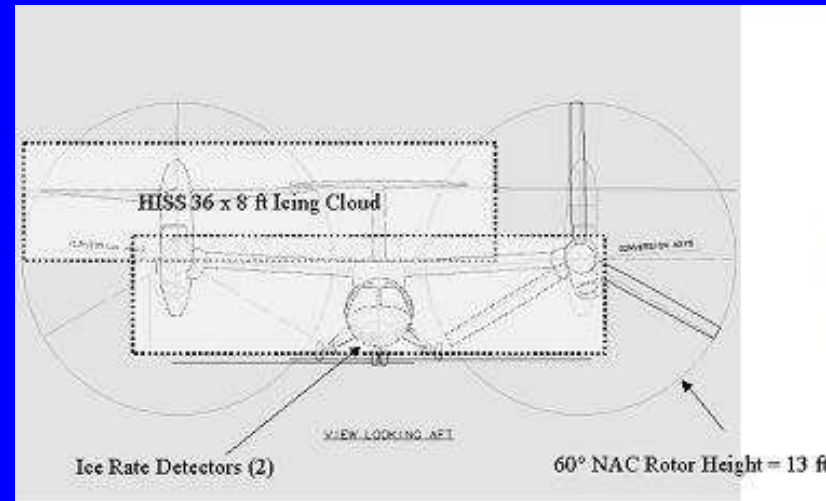
Ice shapes simulating normal operation, sub-system failure, unprotected components (Spinner and Empennage – 45 minutes) and SLD (15 minutes) were applied in combinations and tested. Shapes were generated from the traces taken during the full-scale component icing tests and geometrically scaled.



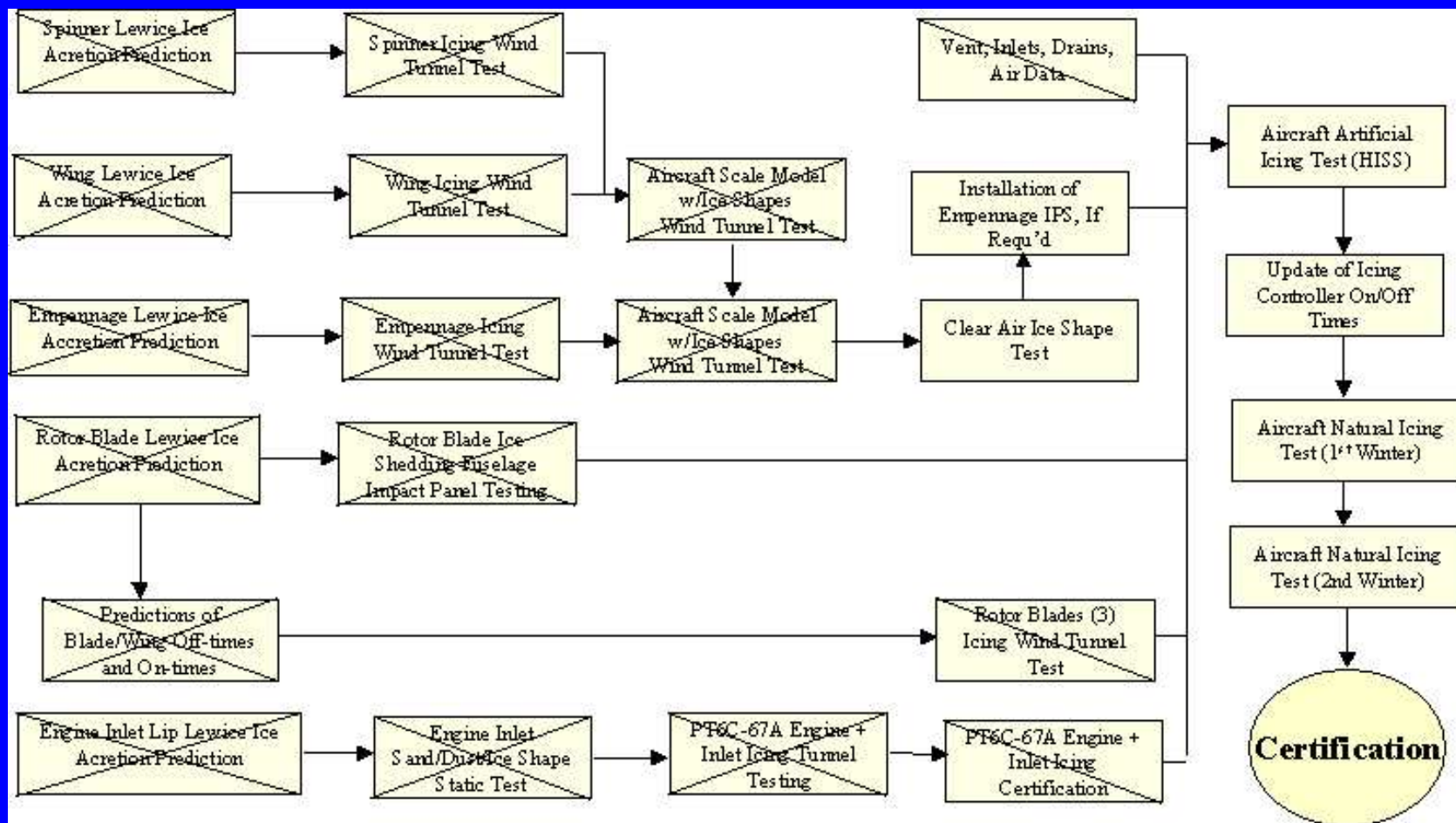
BA609 Certification

The aircraft System Specific Certification Plan (SSCP) has been reviewed with the FAA. Aircraft certification, including clearance for flight into known icing is scheduled for 2007

The HISS is the cornerstone of rotor ice protection certification. To date, there is no other tool available where a full-scale rotor could be immersed into a representative controlled cloud. Failure modes of the rotor ice protection system can be safely evaluated prior to proceeding with aircraft natural icing.



BA609 Plan to Certification



Conclusions

From the earlier testing of a Model 47 at Mt Washington to the development of a CFD icing code allowing evaluation of aircraft performance many icing tests were conducted by Bell Helicopter. From each tests lessons are learned and are applied to subsequent projects.

There are yet many lessons to learn in resuming the V-22 flight test in natural icing conditions that will be directly applicable to future Tiltrotor projects.

A lot more is to be done to reduce the cost of such projects. CFD icing codes, by eventually being validated and accepted as certification tools, will significantly reduce the risks and costs of certification for flight into known icing.